Sustainable Geotechnical Construction with Recycled Materials

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Why is Sustainability Important?

- Nexus of major issues caused by rapidly growing global economy:
  - Global warming
  - Energy constraints
  - Resource availability (metals, cement, oil etc.)

- World population is 6 billion (B) → 12 B projected by 2100. US at 0.5B by 2050.

- US and EU (combined population = 0.75 B) consume most of world resources. China catching up fast.

- Remaining 5.25 B want everything we have. Not enough to go around if we do business as usual.
How Can We Make Infrastructure Construction More Sustainable?

1. Reduce energy consumed in construction and rehabilitation.
2. Reduce emissions emitted in construction and rehabilitation.
3. Reduce consumption of natural resources.
4. Increase service life and lower cost.

Triple Bottom Line: Environment, Economics, Society
How Do Recycled Materials Fit In?

1. Avoid energy and emissions associated with mining and processing construction materials. Energy has already been expended in first life of recycled material.

2. Avoid use of a natural resource (sand and gravel, limestone, oil).

3. Increase service life. Not an “infrastructure landfill,” but comparable or better/longer lasting infrastructure

4. Capital and life cycle costs can be lower (economic sustainability).
Safe and Wise Principle

- Promote the **safe** and **wise** use of recycled materials in construction of transportation infrastructure through education, technology transfer, and applied research.

- **Wise** ... ensure that the recycled material is suitable for the highway environment and provide procedures for appropriate use.

- **Safe** .... ensure that material will not have an adverse impact on the environment or users.
Recap Poll # 1 – True or False

• Climate change is the biggest driver behind sustainability considerations infrastructure: T/F

• Energy savings is a primary advantage of using recycled materials in construction: T/F

• Sustainability triple bottom line is social, economic, and political issues: T/F

• Safe and wise principle is ensuring recycled materials do not adversely impact environment and make sense from civil engineering perspective: T/F
Coarse-Grained Recycled Materials

- Recycled concrete aggregate
- Recycled asphalt concrete
- Foundry sand from iron casting (low bentonite)
- Bottom ash from coal combustion
- Crushed and mixed glass
- Wood chips
- Shingle shreds
- Tire shreds
- Shredded plastics and crushed thermoset plastics
- Polystyrene foam
Recycled concrete aggregate (RCA) from building demolition – note brick fragments, reddish color, and high fraction of finer particles. More sensitive to water softening.

Recycled concrete aggregate (RCA) from pavement – clean and angular particles. Stiff material compared with RCA with brick. Residual cements bind particles together when moistened.
Bottom ash – looks like sand, but has lower specific gravity and particles more prone to crushing. Can have contaminants (see chunk at upper left).

Grey-iron slag – looks like pea gravel. This slag is porous, like tuff, because it was quenched in water. More prone to particle crushing than natural aggregate. Air-cooled slags not as porous.
RAP – residual asphalt coating particles. Stick from asphalt brings up strength and stiffness, but also creep. For example, will rut more readily than conventional aggregate.

RAP and some RCA. Blend probably from milling of HMA overlay over a concrete pavement.
Shredded “tear-off” shingles contaminated with wood chips. Lightweight, but compressible, creeps, and temperature sensitive.

Grey-iron foundry sand with low bentonite content. Black color from sea coal used as reducing agent. More moisture sensitive when higher bentonite content.
Applications

• Structural fill for slabs and retaining walls
• Lightweight fill (tires, foams, crushed thermosets)
• Embankments
• Base and sub-base for pavements
• Drainage media
Fine-Grained Recycled Materials

• Fly ash (self-cementing & non-cementing)
• Flue-gas desulphurization (FGD) sludges
• Foundry slag from iron casting (higher bentonite content)
• Papermill residuals (“sludges”)
• Dredge spoils
Soft paper sludge used as barrier.

Powdery fly ashes and close up of fly ash particles.
FGD gypsum – may be used to address plasticity, but problems with ettringite. Used as agricultural amendment or for drywall production.

FGD filter cake. Not useful alone, but may be blended with cementitious fly ashes.
Applications

• Fill in applications where lower strength and higher compressibility are acceptable.

• High strength fill when blended with other materials (e.g., with cementitious fly ash).

• Cementing and stabilization of soils.

• Hydraulic barriers
Other Examples of Recycled Materials in Geotechnical Construction

- Piling manufactured with recycled plastic
- Recycled plastic pins for slope stabilization
- Geosynthetics from recycled polymers.
- Strength enhancement using shredded reclaimed plastics or fibers

Design with these materials generally follows conventional methods, but with consideration of different material source (e.g., stiffness, durability, creep).
Practical Factors to Consider

• Volume availability, source, & delivery price
• Consistency – varies between materials & suppliers
• Special handling needs – Dusting? Moisture?
• Regulatory permitting
• Engineering properties – available? Measured?
• Past experience
Geotechnical Considerations

- Shear strength
- Compressibility
- Hydraulic conductivity
- Durability – wetting & drying, freezing & thawing, handling
- Reactivity – cementing, heating, swelling
- Leaching – release of trace elements, organic compounds
- Coarse vs. fine materials
- Test scale, drainage conditions
Shear Strength of Foundry Sands

- Friction angle not sensitive to fines or bentonite content, except when bentonite content gets higher.

- Reasonable to use 36° for many sands, except high bentonite content.
Foundry sands are poorly draining unless bentonite content is low.
Resilient Modulus of RAP and RCA

\[ M_r = k_1 \theta^{k_2} \]

\( \theta \) = bulk stress

\( k_1 \) and \( k_2 \) = fitting parameters

Summary resilient modulus (SMR) at bulk stress = 208 kPa.
• RCA, RAP, RPM all have higher SRM than Class 5.
• Not sensitive to gradation. Similar for each RAP, RCA, or RPM
• Recommended SRM:
  • RCA = 180 MPa
  • RAP = 150 MPa
  • RPM = 150 MPa
Large-Scale Testing Equipment

- Large-scale testing equipment may be required for recycled materials with large particles.

- Analogous to large-scale testing of gravels and cobbly materials for dams.

- Use caution when scalping materials and testing residual in conventional test cells.
Recap Poll # 2 – True or False

• RCA from buildings and pavements is the same: T/F

• Shredded shingles can be used as light weight fill, but are compressible prone to creep: T/F

• Foundry sands have essentially the same engineering properties regardless of source: T/F

• Papermill residuals (sludges) can be used as hydraulic barrier materials: T/F
Environmental Considerations

• Ground water is the most common environmental consideration – leaching of constituents that may impair drinking water.

• Surface water can be an issue for embankments and other earth structures above grade if side seeps occur or internal drainage provided.

• Air quality can be a concern for fine-grained non-plastic materials – fly ash.

• No federal regulations or guidance. Some states have rules or ‘beneficial use determinations’ (BUDs).
- Evaluate byproducts based on total elemental analysis and water leach tests.

- Define byproduct categories based on test data.

- Define suitable application based on category.
Applications Based on Category

Lower category number provides more stringent limits on leaching characteristics.
Water Leach Test Criteria – NR 538

- Contaminants of concern depend on byproduct being considered.
- Category 1 has the most test requirements.
Lab Methods to Assess Leaching

• **Batch tests:**
  - solid and liquid in a vial
  - tumbled to ensure local well-stirred
  - supernatant analyzed for contaminants of concern

• **Column tests:**
  - flow through experiment simulating field scenario
  - effluent analyzed for contaminants of concern.
Leachate collected in drum analyzed for volume transmitted and trace elements.
Field Methods: Lysimeter for Direct Measurement

- Geomembrane installation
- Sump welding
- Collection tank installation
- Drainage layer installation
Hg is well below MCL. No difference between conventional and recycled materials.
WiscLEACH Model

Byroducts Layer
Subgrade
Pavement
Base
Vadose Zone Flow & Transport
Ground Water Table (GWT)
Point of Compliance (POC)
Ground Water Flow
WiscLEACH Model

Ground Water Transport

Ground Water Flow

GWT

L

W_s

W_p

W_{poc}

W_s

Z_{GWT}

Z

Z_B

Z_T
Recap Poll # 3 – True or False

• Federal regulations govern the use of recycled materials in geotechnical construction: T/F

• States have regulations to follow regarding using recycled materials in construction: T/F

• Batch tests are the most common tests to evaluate leaching from recycled materials: T/F

• Control tests are un-necessary and provide extraneous data: T/F
Sustainability Metrics & Life Cycle Assessment Tools

- Life cycle analysis (LCA) to assess variety of sustainability metrics (energy, GHG emissions, water use, hazardous waste generation, etc.).

- Life cycle cost analysis (LCCA) to evaluate life cycle cost of design alternatives.

- Quantitative and auditable metrics.
BE$^{2}$ST Highway Sustainability Rating System
Stabilizing RPM with Off-Spec Cementitous Fly Ash at MnROAD

MnROAD is a full-scale highway test facility operated by Minnesota DOT.

Tuncer B. Edil, RMRC, PI

US DoE & RMRC
Two Byproducts $\rightarrow$ Useful Product

RPM + High Carbon Fly Ash = high modulus and durable base
MnROAD Test Sections

- Conventional Aggregate Base
- RPM Base
- RPM + Fly Ash Base

Riverside 8 Fly Ash from Xcel Energy, 14.6% LOI and 22% CaO Non-compliant with MCPA requirements.
Placement of RPM and Fly Ash
Mixing & Compaction
HMA Paving
Pavement Performance - Modulus

Modulus from LWD, MPa

- LWD, 7days
- DCP, 7days
- DCP 21days
- FWD, 21 days
- SSG, 21days

Base Courses Materials

RPM
Crushed Aggregate
RPM+FA
Construction Life Cycle Analysis – Energy Usage

Most energy: Conventional construction material.

Least energy: recycled pavement in place of crushed aggregate.
Construction Life Cycle Analysis – GHGs

Most emissions: Conventional construction material

Least emissions: recycled pavement in place of crushed aggregate
Recap Poll # 4 – True or False

• Life cycle analysis and life cycle cost analysis are essentially the same thing: T/F

• Sustainability metrics include energy consumption, greenhouse gas emissions, and water usage: T/F

• Using recycled materials in construction can reduce energy emissions and greenhouse gas emissions: T/F

• Recycled materials always have inferior properties relative to conventional construction materials: T/F
Comparison of Alternatives using BE$^2$ST

- HMA = hot mix asphalt
- RAP – reintroducing reclaimed asphalt into new hot mix asphalt
- RPM – using RAP as granular base
- SPRM – using RAP + fly ash binder as base.
Comparison of Alternatives using BE\(^2\)ST in Highways

**HMA 5 ½”**
- Base Aggregate 6”
- Subgrade

**HMA-5 ½” (RAP 15%)**
- Base Aggregate 6”
- Subgrade

**HMA 5 ½”**
- RPM 6”
- Subgrade

**HMA-5 ½” (RAP 15%)**
- RPM with 10% FA 2.8”
- Subgrade

**HMA-5 ½”**
- RPM 6”
- Subgrade

**HMA-SRPM**
- RPM with 10% FA 2.8”
- Subgrade

**HMA-5 ½” (RAP 15%)**
- RPM with 10% FA 2.8”
- Subgrade

**HMA-RAP-SRPM**
- HMA-5 ½” (RAP 15%)
Life Cycle Energy Consumption

Most energy: reintroducing reclaimed asphalt into HMA.

Least energy: using stabilized reclaimed asphalt in base and RAP in HMA.
Most emissions: introducing reclaimed asphalt into HMA.

Least emissions: using stabilized reclaimed asphalt in base & RAP in HMA.
Least expensive: using stabilized reclaimed asphalt (SRPM) in base and RAP in HMA.

Most expensive: reclaimed asphalt in hot mix asphalt (HMA)
What's New

The latest RMRC Quarterly Newsletter is now on-line. Check it out [here](http://www.recycledmaterials.org).

A draft Final Report for Project 60, *Quantifying the Benefits of Using CCPs in Sustainable Construction*, is now available [here](http://www.recycledmaterials.org).

Environmental Issues of Recycling Tear-Off Roofing Shingles Webinar

On October 7, NAPA, WasteCap Resource Solutions, CMRA, and Wisconsin DNR produced a webinar entitled, *Environmental Issues of Recycling Tear-Off Roofing Shingles*. The webinar was attended by 125 participants from around the continent and lasted for almost two hours. A broad range of environmental and other regulatory issues were discussed, including case study highlights from Minnesota and Wisconsin. A PDF of the handouts can be found [here](http://www.recycledmaterials.org).

RMRC in the News

Green roads: Highways of the future?

Article about the problems we face with the planet’s fast-growing road systems. [More](http://www.recycledmaterials.org).

US Infrastructure, 09:10:09

Features

User Guidelines for Byproducts and Secondary Use Materials in Pavement Construction

The User Guidelines have recently been updated with new materials and new evaluation guidance. Check it out [here](http://www.recycledmaterials.org).

PaLATE

This computer-based life-cycle cost analysis (LCCA) tool uses environmental parameters to assist decision-makers in evaluating the use of recycled materials. Download now [here](http://www.recycledmaterials.org).

RMRC Foundry Sand Webinar

The RMRC sponsored a series of 6 webinars on the use of foundry sands in transportation and infrastructure applications in the fall of 2008. To view the streamed presentations, click [here](http://www.recycledmaterials.org).